Vision, Modeling, and Visualization (2013)
Michael Bronstein, Jean Favre, and Kai Hormann (Eds.)

Evaluating the Perceptual Impact of Rendering Techniques on Thematic Color Mappings in 3D Virtual Environments

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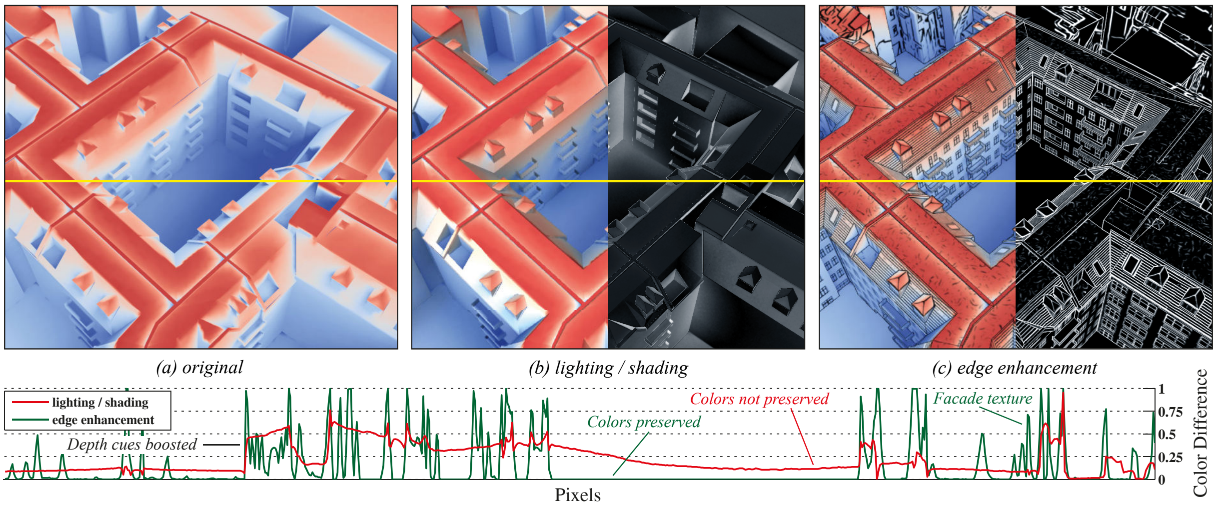

Figure 1: *Visualization of thematic data in a 3D virtual environment using a diverging blue-red color scheme: (a) original output, (b) visualization enhanced by Blinn-Phong shading and screen-space ambient occlusion, (c) visualization enhanced by an image-space edge detection based on depth, normal, and object information combined with a difference-of-Gaussians filter for façade textures. Euclidean RGB color differences of (b) and (c) to (a) are illustrated respectively; the scanline plots at the bottom illustrate the effect of boosted depth cues but altered color information along the yellow lines. As can be seen, lighting, shading and edge enhancement alter colors in a different way, whose impact on the perception of thematic information is evaluated in our quantitative and qualitative user study.*

Abstract

Using colors for thematic mapping is a fundamental approach in visualization, and has become essential for 3D virtual environments to effectively communicate multidimensional, thematic information. Preserving depth cues within these environments to emphasize spatial relations between geospatial features remains an important issue. A variety of rendering techniques have been developed to preserve depth cues in 3D information visualization, including shading, global illumination, and image stylization. However, these techniques alter color values, which may lead to ambiguity in a color mapping and loss of information. Depending on the applied rendering techniques and color mapping, this loss should be reduced while still preserving depth cues when communicating thematic information. This paper presents the results of a quantitative and qualitative user study that evaluates the impact of rendering techniques on information and spatial perception when using visualization of thematic data in 3D virtual environments. We report the results of this study with respect to four perception-related tasks, showing significant differences in error rate and task completion time for different rendering techniques and color mappings.

Categories and Subject Descriptors (according to ACM CCS): Computer Graphics [I.3.3]: Three-Dimensional Graphics and Realism—Display Algorithms

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DOI: 10.2312/PE.VMV.VMV13.025-032

1. Introduction

3D geovirtual environments represent essential tools for the effective visualization and management of complex, multi-dimensional geospatial data, such as virtual 3D city models. Thematic data represents an integral part of geospatial data along geometry, topology, semantics, and appearance (CityGML [Kol09]). In contrast to semantics, thematic data is usually modelled by a fine-scale function of surface positions, encoded as surface data in textures and visualized using a thematic color mapping with texturing capabilities of graphics hardware [DK00]. For instance, the results of a solar potential [ED10], crime [Wol10], or heat transmission analysis may be mapped to colors using color maps known from cartographic design [Mac04].

Human eyes project 3D virtual environments onto two-dimensional retinas, where depth sensation is generated by subconscious interpretation of depth cues. Depth cues are essential for perceiving model contents as three-dimensional and for mental modeling to estimate relative positions, sizes, distances, and shapes [CV95, Pfa00, Gol10]. A variety of rendering techniques exist to enhance pictorial (monocular) depth cues, such as shading, global illumination, and edge enhancement [AMHH08]. Combined with color-encoded thematic information, however, these techniques alter color information (Figure 1), thus, colors may not (or ambiguously) be mapped to thematic information, requiring additional mental effort. Moreover, applying thematic textures may omit structural information that is not explicitly modeled as geometry but captured by aerial or terrestrial imaging (e.g., building façades). This information is often essential for landmark identification and mental modeling [Lyn60], but neither can be enhanced by illumination techniques as no geometry is involved, nor by image blending as it would distort thematic and appearance information.

Several research questions arise when using rendering techniques with thematic color mappings to enhance depth cues in 3D virtual environments: (1) To which degree these techniques improve the orientation in 3D and creation of mental maps, (2) if they improve the perception and estimation of distances, (3) if they alter the perception of the visualized thematic data, (4) if certain rendering techniques perform better for thematic visualization than others, and (5) if a combination of rendering techniques always improves the orientation and distance estimation. We performed a quantitative and qualitative user study that addresses these questions. Participants performed four perception related tasks in a thematic visualization of a virtual 3D city model with different enhancement rendering techniques and color mappings. Among the examined rendering techniques, the main findings of the user study are that (1) all techniques reduce the time required for orientation in a 3D virtual environment and creation of a mental map, (2) thereby, abstract façade textures improve the performance most, (3) these techniques have an opposed effect on a point-wise and area-wise estimation of thematic values, (4) all techniques reduce the accuracy of a point-wise estimation, but increase the accuracy of an area-wise estimation, (5) local illumination is the least suitable for an accurate point-wise estimation, (6) edge enhancement is the most suited technique for an accurate area-wise estimation, and (7) a combination of techniques shows no pattern compared to the individual ones regarding performance and, thus, need to be evaluated individually.

The remainder of this paper is structured as follows. Section 2 reviews related works on the visualization of thematic data, color perception, and interactive enhancement rendering techniques for 3D virtual environments. Section 3 describes the design, procedure, and results of our user study. In Section 4 these results are discussed. Finally, Section 5 concludes this paper and states ideas for future work.

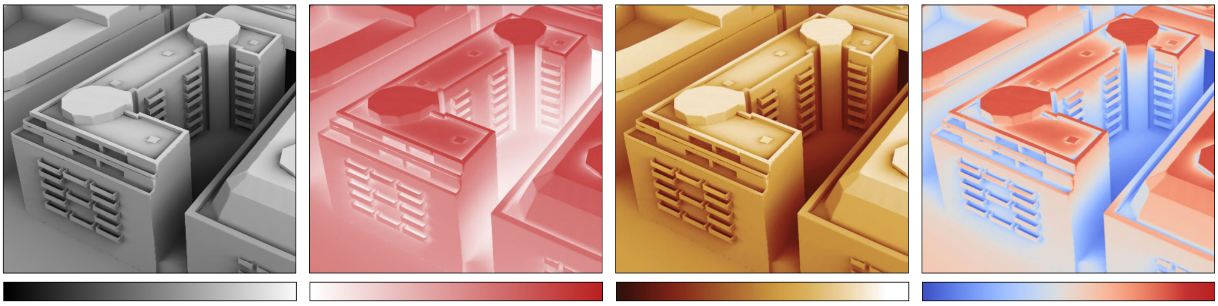
2. Background

Our work is related to previous works on color mappings used for thematic data and rendering techniques used to enhance visualization in 3D virtual environments.

2.1. Color Mappings for Thematic Data

Color maps (or ramps) are often used in urban simulations for data visualization, for instance by capturing location-dependent data on feature surfaces (e.g., façade properties [LD10]). However, their usage in 3D virtual environments to represent thematic data has so far not been widely discussed. Previous work showed that the perceived color for a certain location depends on the surrounding visual context [Lan59], and that the perceived color of an area may shift towards the opposite color of the surrounding area [Bre92]. Another effect called *color constancy* is observed when the same color is perceived identical under different lighting conditions. This implies that spectral properties are estimated subconsciously by subtracting the effect of lighting [TFCRS11]. Previous work explored color hues as a visual variable in 3D maps [FVS05], but only for nominal data, thus considering only color maps with distinct, well-defined colors.

Using color maps for cartography-oriented visualization of 2D data is well researched. Color schemes with varying luminance are well-suited for high-frequency data, whereas saturation-based schemes are for low-frequency data [RT09]. A well-known approach to use the hue as variable is described by a rainbow (spectral) color map. However, using this kind of maps, there is no intuitive order among all colors and the perceived difference of colors varies as a function of hue as well as the ability to discriminate similar colors [BT07,TFCRS11]. Hue-based color maps can be improved by including luminance as a second redundant variable. A black-body radiation (BBR) imitates the color change of a black object when heated [LH92] and has a variation in luminance over the whole range (Figure 2c). It is perceived more naturally and exploits the higher sensitivity for orange and yellow colors, but at the cost that the sensitivity for luminance drops quite quickly for low values [Kan99]. Another approach is to use a color map with



(a) Monochrome *(b) Continuous, single hue* *(c) Desaturated black-body radiation* *(d) Diverging*

Figure 2: *Thematic information visualized using different color mappings, where (b), (c), and (d) were used in our user study.*

a single hue and varying saturation. In this way, luminance can be used to encode another thematic variable. Two single-hue color maps can be combined to a diverging color map [Mor09], which is especially suited for data that is classified into low and high values. For our user study, we used a diverging blue-red color map, a continuous, single-hue white-red color map, and a warm, desaturated BBR (Figure 2).

2.2. Rendering Techniques for Depth-Cue Enhancement

Prominent approaches for depth-cue enhancement can be found in non-photorealistic rendering, shading, and lighting.

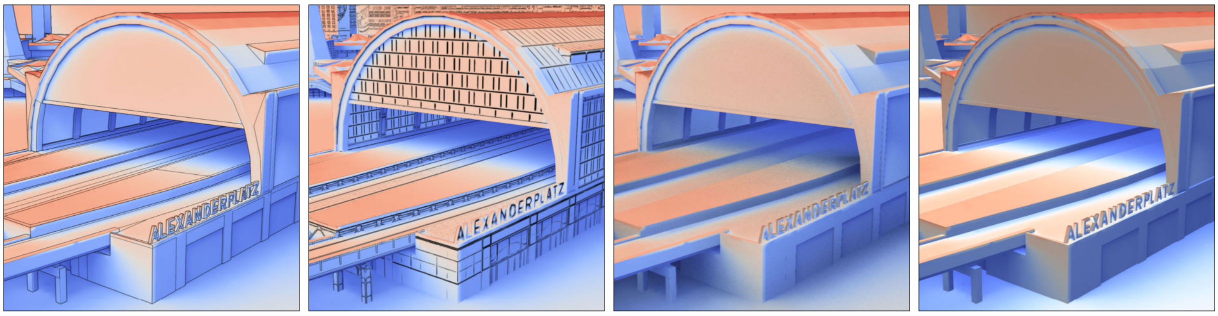
Edge Enhancement and Image Abstraction. Edge information conveys the most important structure information of an image [WKO12] by making objects more clearly distinct, given the limited dynamic range of an image ([War04], p. 78). In non-photorealistic rendering (e.g., Toon or Gooch shading [GGSC98]) and visualization of technical 3D models [ND03], outlines are used to discriminate between different features or to communicate fuzziness. Edge enhancement is also prominently used in medical visualization to detect local non-linear contrast changes and enhance boundaries between materials, which has proven to be more effective in terms of viewing time [LNM95,KRL*01]. The impact of edge enhancement on thematic color mappings within 3D virtual environment with respect to shape recognition (e.g., building elements) has not been widely discussed. For an interactive image synthesis, edge enhancement techniques can be generally classified into *object-based* [DW03] and *image-based* [ST90] approaches. Object-based edge enhancement offers more artistic control over different edge styles, but often requires to pre-process a 3D scene. For our user study we selected an image-based approach [ND03] that performs at real-time frame rates (Figure 3a).

To highlight specific façade properties within 3D virtual environments, it is often necessary to convey surface details so that thematic data can be mapped to object features, such as windows or doors of 3D buildings models. Previous works proposed two approaches: (1) edge enhancement filters working in image-space to pre-process façade textures, combined with image blending to enhance color information [SKD10], and (2) procedural texturing based on texture prototypes, e.g., randomly placed on building façades [BDNK05]. For our user study, we used a dfference-of-Gaussians filter [WKO12] since it adjusts to image contents and facilitates the visual discrimination of façade features (e.g., doors or windows) (Figure 3b).

Local and Global Illumination. Local illumination techniques (e.g., Blinn-Phong shading [Bli77]) are well established in computer graphics and scientific visualization due to their low computational cost and integration into the standardized rendering pipeline [AMHH08]. However, they are not suitable for a physically-correct illumination as they do not consider object occlusions. By contrast, global illumination techniques, in particular the *ambient occlusion*, became quite popular in real-time photorealistic rendering as they offer a higher degree of realism. In general, global illumination enables to explore data more easily by enhancing the perception of depth cues and local thickness of volume data [ZM13], and is suitable to communicate subtle changes in 3D structures (e.g., for particle simulations [GBP08]). However, it is rarely used in scientific visualization because of the high computational cost, and, to our best knowledge, has so far not been evaluated regarding the impact on thematic color mappings. There are two major approaches to approximate global illumination for polygon-based 3D virtual environments. First, a pre-computation using light maps [GWS05] for static representations. Here, the results are stored in additional texture maps, which requires more memory but offers more realistic results. Second, a real-time image-based approximation for dynamic scenes by computing only local variances in contrast and shading [RGS09]. For our user study we selected an image-based approach due to its high flexibility (Figure 3c).

3. Experiment

We performed a quantitative and qualitative user study to objectively compare and evaluate the different rendering techniques and color mappings identified in Section 2. The participants had to perceive color-encoded thematic information in a 3D virtual environment for value estimation and localization tasks. The purpose of this study was to determine if



(a) Edge Enhancement *(b) Abstract Façade Textures* *(c) Screen-Space Ambient Occlusion* *(d) Blinn-Phong Shading*

Figure 3: *Comparison of different enhancement rendering techniques examined in our user study.*

there is a significant main effect on the rendering techniques and color mappings, and which ones allow participants to perform their tasks fastest and with highest accuracy.

3.1. Data Set

The virtual 3D city model used for the user study represents a 1.8 km^2 central urban area of Berlin, Germany, which includes the results of a solar potential analysis as thematic data [ED10]. The solar potential was pre-computed by a radiation summed up over a whole year, taking into account surface orientations and shadowing of neighboring objects, and mapped onto a continuous range between 0 and 1.

3.2. Tasks

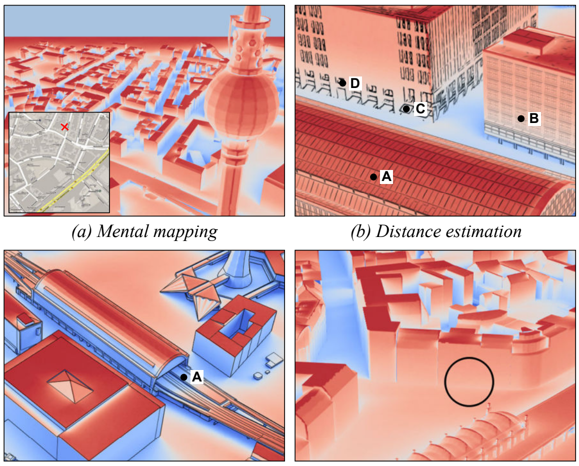
The participants were asked to perform four different tasks (Figure 4), and were instructed to complete each task as quickly as possible while maintaining reasonable accuracy.

Task 1 – "Mental Mapping": Participants had to locate a point-of-interest in the 3D view that was shown as a red cross on a separate 2D map next to the visualized virtual 3D city model. The 2D map was obtained from Google Maps at zoom level 14, which included tertiary roads and buildings from an isometric perspective (Figure 4a). Participants were asked to left-click with a mouse onto the target position in the 3D view and were allowed to correct this position.

Task 2 – "Distance estimation": The 3D view displayed four points-of-interest, each marked and labeled from A to D. The participant's task was to estimate which one of the points B, C or D was located closest to point A (Figure 4b). The participants were asked to estimate the direct Euclidean distance in 3D space, ignoring possible intersections. If a participant was unsure, a trial could be skipped.

Task 3 – "Point-wise value estimation": Participants had to estimate the solar potential at a point-of-interest (Figure 4c). For a given color mapping, a scale from 0 to 100 percent was shown at the bottom of the 3D view as orientation guidance.

Task 4 – "Area-wise value estimation": Similar to task 3, the participants had to estimate the average solar potential within an area-of-interest that was highlighted in the 3D view by a black circle with a radius of 50 pixels (Figure 4d).



(a) Mental mapping *(b) Distance estimation*

(c) Point-wise value estimation *(d) Area-wise value estimation*

Figure 4: *Exemplary trials for the tasks of our user study.*

3.3. Participants

We recruited 21 volunteers (17 male) between the ages 21 and 49 of which most (19) were undergraduates in software engineering or staff members from our campus. While all of them had experience with computers, three had no or only little experience with 3D graphics applications (e.g., CAD, computer games, GIS). All of them had normal or corrected-to-normal vision and no known visual impairments.

3.4. Experimental Design

We conducted a quantitative and qualitative user study with the previously described tasks. The study design was within subjects $4 \times 3 \times 8$ (task $\times$ color mapping $\times$ rendering technique), which resulted in a total of 96 trials per participant. The rendering techniques comprised Blinn-Phong shading, SSAO, image-space edge enhancement, and blending of abstract façade textures (Figure 3); the other four were either combinations (i.e., Blinn-Phong shading+SSAO, abstract façade textures+SSAO, and abstract façade textures+edge enhancement) or a plain color mapping without additional modification as reference comparison. Because the study was designed to evaluate the impact of these rendering techniques, we limited the number of color mappings to three: a warm, desaturated black-body radiation (BBR), a diverging blue-red color scheme, and a continuous white-red color scheme with a single hue (Figure 2). The BBR was used to have a greater variety among the color maps due to its luminance changes that might interfere with luminance changes introduced by the rendering techniques. For all trials, each combination of color mapping and rendering technique was setup for a distinct random camera setting.

An additional trial at the beginning of each task was counted as practicing so that the participants got familiar with the task and user interface. The task and trial order were counterbalanced between subjects to avoid sequence effects. Participants received verbal instructions prior to every task, and upon their completion they rated the usefulness of each rendering technique for all color mappings, rated on a scale from 0–"not useful at all" to 7–"very useful". There was no time limit and the participants had the possibility to skip trials or correct their answers. In addition to the independent variables (i.e., task, rendering technique, color mapping), the completion time and quantitative error measures for the respective trials were recorded, i.e., the distance error in image-space for task 1, if the correct point was selected for task 2, and the absolute error in percentage for task 3 and 4. The study took about 45 minutes per participant and each one received a bar of chocolate as a gratuity for their time.

3.5. Apparatus

All participants used the same two-monitor setup (24 inch, TFT, 1920×1200 pixels) with equal color settings under standard room lighting conditions (Figure 5). The 3D views of the model were rendered in real-time, could not be adjusted by camera navigation, and were displayed on the first monitor on a 1920×1080 pixel area. The remaining pixels were used to present a normalized legend (values between 0 and 100) of the active color mapping with marks visualized every 10 units. The second monitor was used to display the interface elements for the answers, and a 2D map (900×900 pixels) for task 1. The interface included radio buttons for task 2 and spin boxes task 3 and 4. All participants had the possibility to adjust the chair and monitor height, orientation, and distance to their comfortable settings.

3.6. Hypotheses

We had the following hypotheses for our user study:

H1. All rendering techniques would improve the spatial perception and, thus, would reduce task time and error rate for mental mapping and distance estimation.

H2. The estimation of thematic values would be more difficult with any rendering technique and would result in higher error rates and task completion times.

H3. There would be significant main effects between color mappings and the tasks' completion times and error rates.

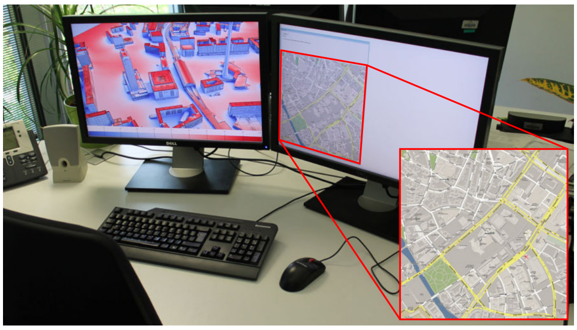


Figure 5: *Experimental setup that exemplary shows the user interface of the "mental mapping" task.*

H4. There would be a distinct order of rendering techniques and color mappings for each task.

H5. Compared to individual rendering techniques, a combination would improve the participants' performance in task 1 and 2 but increase the error rate in task 3 and 4.

3.7. Results

For all tasks we performed a separate 8×3 (rendering technique × color mapping) repeated measures ANOVA. The apparatus allowed to skip questions, and in some trials the subjects unintentionally skipped a trial by clicking twice on the "Next" button, which resulted in 4.1% missing answers. Because the repeated measures ANOVA required complete data sets for each subject and discarding subjects would have thinned out the data set, multiple imputations were performed for each task to complete missing data. The analysis was performed on each of the five created imputations and results were combined by creating mean values. In the following, reported numbers (e.g., F and p-values) refer to their mean of the five imputations.

Task 1 – "Mental Mapping": An error of over 50 pixels in screen-space was classified as missing the target position, which resulted in 6.6% failure trials among the participants. However, this number was too small to find any significant main effects on color mapping or rendering technique, which also applies for our analysis on the task's completion time summarized in Figure 7a. All rendering techniques improved the completion time by at least 6.4% over using no enhancement (i.e., using a plain color mapping). The participants performed faster by 25.7% in average when abstract façade textures were applied. Among the color mappings, the average completion time using BBR was 15.1% longer than using the other two color mappings.

Task 2 – "Distance estimation": Evaluating the percentage of correct answers, we did not find any significant main effect on rendering technique or color mapping. The same applies for the task completion time, where participants performed 14% (1.8s) worse than the overall average when abstract façade textures were applied (Figure 7b).

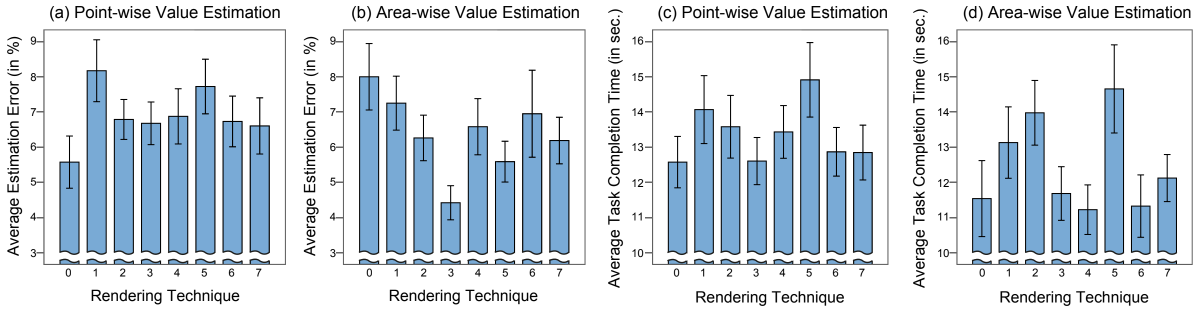


Figure 6: *Error and task completion times for value estimation with (0) no enhancement, (1) Blinn-Phong shading, (2) SSAO, (3) edge enhancement (EE), (4) abstract façade textures (AFT), (5) Blinn-Phong shading+SSAO, (6) SSAO+AFT, (7) AFT+EE.*

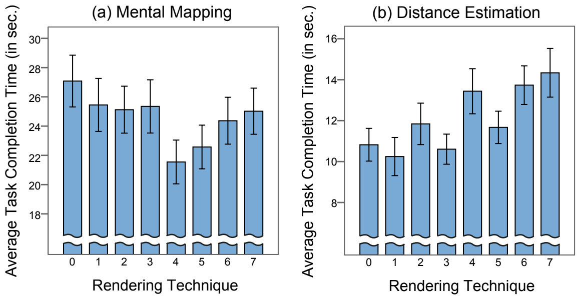


Figure 7: *Task completion time for the mental mapping and distance estimation tasks (see Figure 6 for disambiguation).*

Task 3 – "Point-wise value estimation": Using a repeated measures ANOVA for the average error in the point-wise value estimation, we found a significant main effect on color mapping ($p < 0.001$, $F_{2,20} = 43.08$). Post-hoc comparisons using Bonferroni corrected p-values found significant differences between all three color mappings (all $p < 0.001$). The estimation was 60.6% less accurate using the white-red color mapping than with the BBR color mapping, which in turn was 44.4% less accurate than the diverging color mapping (Figure 8). The average error for each rendering technique is summarized in Figure 6a. All rendering techniques were at least 18.5% less accurate than without using any enhancement, where the techniques using Blinn-Phong shading performed worst with 46.7% and 38.6% less accuracy. The repeated measures ANOVA found no significant main effect on rendering technique ($p = 0.067$) and no interaction between rendering technique and color mapping.

Evaluating the completion time, we found no significant main effect on either rendering technique, color mapping, or the interaction between them. The task completion time was almost the same among all color mappings, but the effect of rendering techniques corresponds to that regarding the estimation error. The participants took 11.9% and 18.6% more time for a trial when using Blinn-Phong shading than without using any enhancement (Figure 6c), and only up to 8% more time for the other techniques.

Task 4 – "Area-wise value estimation": Figure 6b summarizes the average error rate for this task, showing that the participants had the highest error rate when using a plain color mapping (i.e., without any enhancement), followed by Blinn-Phong shading being 9.4% more accurate. The highest accuracy was performed with the image-space edge enhancement technique, in average, 44.6% better than with a plain color mapping, whereas the other techniques performed between 13.1% and 30.1% better. Using a repeated measures ANOVA we found a significant main effect on rendering technique ($p < 0.05$, $F_{7,15} = 3.25$). Post-hoc pairwise comparisons using Bonferroni corrected p-values showed significance in the effect of image-space edge enhancement. We also found a significant main effect on color mapping ($p < 0.001$, $F_{2,20} = 33.28$), and post-hoc comparisons using Bonferroni corrected p-values found significant differences between all three color mappings (all $p < 0.001$). Regarding the error rate (Figure 8), the participants were 34.8% less accurate with the white-red color mapping than with the BBR, for which in turn they were 53.3% less accurate than the diverging blue-red color mapping. We found no significant interaction between rendering technique and color mapping.

Figure 6d summarizes the average task completion time. Using illumination techniques (Blinn-Phong shading, SSAO) the participants required 13.8% to 27% more time than with any other technique or without any enhancement. Analyzing the effect of the color mapping on task completion time, we also observed that the participants required 8.8% less time using the diverging blue-red mapping. We found no significant main effect on rendering technique and color mapping, and no interaction between them.

Questionnaire: Figure 9 summarizes the results of the questionnaire. The participants reported on task 1 and 2 that the image-space edge enhancement and abstract façade textures (with combinations) helped more than the other rendering techniques, of which the image-space edge enhancement was the most helpful. By contrast, the participants found all techniques with abstract façade textures by far less helpful for task 3 and 4 (value estimation). The ratings for the other techniques were also slightly lower, with image-space edge enhancement rated as the most helpful.

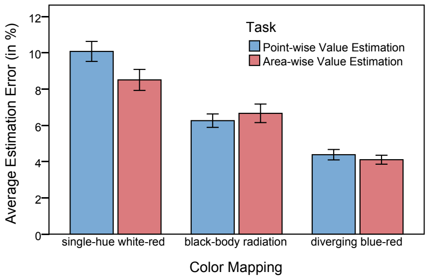


Figure 8: *Comparison between color mappings on the error rate for point-wise and area-wise value estimation.*

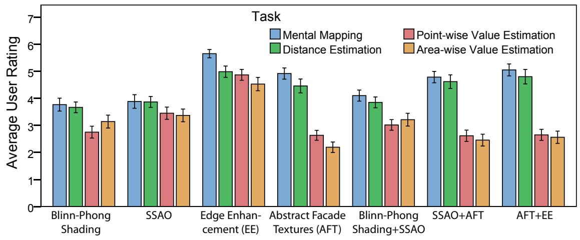


Figure 9: *Results of the questionnaire where rendering techniques where rated from 0 (not helpful) to 7 (highly helpful).*

4. Discussion

Although we did not find any statistical significance for the results of task 1, each rendering technique reduced the mean completion time compared to a plain rendering, which may indicate that they ease mental mapping and orientation guidance. Abstract façade textures improved the task completion time by 25% when locating positions in 3D space, primarily because they provide additional information over the geometric appearance and semantics of buildings to ease the identification of landmarks. By contrast, other rendering techniques showed no specific order in performance.

Task 2 showed no statistical significant performance differences among the rendering techniques and color mappings. Several participants stated that they had difficulties to overview all marked points at a first glance when abstract façade textures were rendered resulting in longer trial times, but stated in the questionnaire that they were quite helpful. This may indicate that they cause visual clutter and special attention should be payed when combining with labels.

Surprisingly, the effect of rendering techniques on the error rate was different for a point-wise and for an area-wise estimation. For a point-wise estimation, our user study confirmed our hypothesis that all examined rendering techniques reduce the accuracy in value estimation (H2). Techniques that constantly change color intensity (e.g., Blinn-Phong shading) showed the greatest decline in accuracy and increased the task completion time, which may be explained by the constant changes in color brightness and altered color information (Figure 1). The altered color either cannot be associated with any value or is mapped ambiguously. The estimation of which color in the color map matches best with the rendered color introduces an additional source of error.

For the area-wise estimation we observed the opposite effect: all rendering techniques reduced the estimation error. Participants reported after the study that they decided about the average color more intuitively rather than trying to calculate exact values by scheme (which would be quite time consuming). Conditioned by everyday experience, the human brain subconsciously deduct color changes caused by illumination, or distraction caused by abstract façade textures. As our results for a plain color mapping indicate, missing any of these effects may rather lead to a wrong subconscious calculation and higher error rates. We did not find any explanation for the particularly good results of the edge enhancement technique, yet. As expected, in both estimation tasks the large-scale changes of the illumination techniques required higher mental effort and longer completion time.

Our user study confirmed our hypothesis that the color mapping has a significant effect on the estimation of values of thematic mappings (H3). We also identified a significant order for both point-wise and area-wise value estimations (H4); using the diverging blue-red color mapping led to the highest accuracy followed by BBR and the white-red single-hue color mapping, which had the lowest accuracy. The diverging color map also reduced the area-wise estimation time compared to the other two color maps. This may be reasoned by the higher color resolution than in the single-hue color map, and lower sensitivity for darker colors of the BBR color map. The high contrast in the BBR color map also seems to interfere with shape perception, which is highly dependent on brightness changes and resulted in longer time for mental mapping. However, we found no interaction effect between rendering techniques and color mappings in any task, even when using the same perceptual channel (e.g., brightness in ambient occlusion and the BBR color map).

Our user study indicates no general effect of combined rendering techniques on color mappings (H5). The combination of the two illumination techniques keeps the penalty for the point-wise value estimation, while rather improving mental mapping and area-wise value estimation. The other combinations negate the positive effects of the individual techniques (i.e., mental mapping using abstract façade textures and area-wise estimation using edge enhancement).

The ratings in the questionnaire only partially coincide with the participants' performance. The edge enhancement and abstract façade textures were rated the most helpful for task 1 and 2. While our user study confirms that abstract façade textures improve the users' performance, the effect of image-space edge enhancement (and combinations) were overrated. The image-space edge enhancement was clearly rated as the most helpful when estimating thematic values, which our results confirm for an area-wise, but not for a point-wise estimation. By contrast, abstract façade textures were clearly underrated for the area-wise estimation than they actually performed.

5. Conclusions and Future Work

This paper presents a qualitative and quantitative user study that confirms that rendering techniques designed for depth-cue enhancement improve the perception of thematic color mappings in 3D virtual environments. Since none of the examined techniques performs best for all tasks, our results indicate that selecting rendering techniques for a 3D thematic visualization requires to consider the visualization purpose. Using abstract façade textures revealed to be a good choice for orientation, navigation, and mental mapping, whereas an edge enhancement improved the estimation of thematic data. Further, our user study confirms that the choice of color mapping effects the perception of thematic values, orientation, and creation of mental maps in 3D.

For future work, we plan to evaluate new approaches that combine multiple rendering techniques and preserve their individual benefits. Possible approaches may involve a distance-based blending or focus-and-context visualization. Further, we plan to implement a generalization scheme of color-encoded thematic data that reduces visual clutter and color ambiguities in far view distances (similar to level-of-detail). Finally, our results indicate that the examined rendering techniques improve mapping of colors to thematic data, which, however, requires further validation.

Acknowledgments

This work was funded by the Federal Ministry of Education and Research (BMBF), Germany within the InnoProfile Transfer research group "4DnD-Vis" (www.4dndvis.de).

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